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HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

COAL-MINE EXPLOSIVES: THEIR CHARACTERISTICS, SELECTION AND SAFE USE

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J. E. TIFFANY

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

COAL-MINE EXPLOSIVES: THEIR CHARACTERISTICS, SELECTION AND SAFE USE.[1] [2]

By J. E. Tiffany[3]

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[1] The Bureau of Mines will welcome the reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7040."

[2] Paper presented before the Coal-Mining Institute of America, Dec. 10, 1937, and published in Proceedings, 51st annual meeting, pp. 35-56.

[3] Explosives testing engineer, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa.

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INTRODUCTION

A stick of explosive is a package of stored energy that can be released when needed to blast rocks, coal, and other materials; but, unlike fuels such as coal and gasoline, its potential energy is self-contained, there being enough oxygen within the package to complete the almost instantaneous reaction. When an explosive is ignited or detonated, the solid or liquid materials of which it is composed are converted rapidly into highly heated gases, which, if free to expand, would have a volume many times larger than that of the original explosive. At the instant of explosion these gases occupy only the volume of the shot hole and are therefore produced at a very high pressure, which causes the material that is being blasted to be broken or disrupted. In blasting coal efficiently the proper placement of the shot hole and the confinement of the explosive therein are both of primo importance. When these are not adjusted properly, only a small amount of the energy is expended in bringing down coal, consequently the balance of the energy tends to be expended by the emission of a flame into the working place that may lead to a gas or dust explosion.

Permissible Explosives Defined

The term "permissible explosive", as applied by the Bureau of Mines to explosives it has approved for use in blasting in coal mines, embraces not only the requirement that the explosive, when used, shall be similar in all respects to the basic sample that passed all the tests necessary for its admission to the published permissible list, but also that the explosive shall be used under certain prescribed requirements.

The most important tests for the determination of permissibility are those in which charges of the explosive are fired from a cannon into a gallery containing explosive mixtures of air and natural gas or air, natural gas, and coal dust. An explosive passes these tests when it does not cause any ignition of the gas mixtures. Other tests are made to determine the strength characteristics of the explosive and also its sensitivity to frictional impact and detonation.

Quantities of Explosives Used

The coal-mining industry in the United States used almost 141,000,000 pounds of explosives in a recent 12-month period, or over one-third of the explosives used for all purposes. Of the explosives used for coal-mining, the percentages of black blasting powder, permissible explosives, and dynamites were, respectively, 46, 35, and 19.

Since May 15, 1909, when the first permissible list of 17 explosives was published by the Technologic Branch of the Geological Survey, over one billion pounds of these explosives have been used, replacing a much larger quantity of black blasting powder. While only about 4 percent of the total quantity of explosives in 1909 were permissible, this figure increased rapidly and in 1919 had increased four times; as already stated, 35 percent of all explosives now used in coal mines are permissibles. The quantity of black blasting powder used at present exceeds that of permissible explosives.

Due to the superior strength characteristics of permissible explosives as compared with black blasting powder, 50 percent may be a fair estimate for the quantity of all coal blasted in the United States by permissible explosives, and it is believed that the mines that use permissible explosives include most of those that might be classed as the more hazardous ones in respect to gas and coal dust.

The dynamites were used mostly in rock-blasting incident to the mining of coal, such as driving tunnels, removing rock roof or floor, and possibly in coal-stripping operations, so that it is quite likely that only a very small quantity was used for blasting coal.

Early Blasting Methods

Prior to the introduction of explosives for making excavations underground, a fire was started at the face to heat the rock; quenching with water caused it to crack and spall. This was known as the fire-setting method.

Before black blasting powder was used as a blasting agent, it is most likely that the pick and wedge were used exclusively for the extraction of coal. Black blasting powder was first used in English mines some time early in the nineteenth century, although it had been known andused in other ways for five centuries. The introduction of black blasting powder opened the way for a rapid increase in the production of coal because the sinking of shafts and making of other openings for the development of coal beds was greatly facilitated.

In the United States prior to 1909 black blasting powder was practically the only explosive used for blasting coal, and its use increased with the ever-increasing production of coal. Unfortunately, however, mine explosions occurred frequently and many of these were caused by the firing of either black blasting powder or dynamite.

Development of Permissible Explosives

Literally, no explosive can be considered entirely safe under each and every condition except in a relative way. As early as 1902, 7 years before the issuance in 1909 of a permissible list of explosives by the United States Government, manufacturers had introduced modified dynamites with a view to decreasing the ignition hazards attending the firing of shots in coal mines. Subsequent study and research regarding the safety, efficiency, and economical use of a large variety of explosives has led to the development of what are now termed in the United States permissible explosives. These explosives are not nearly as likely to ignite explosive mine atmospheres as are the explosives that will not pass the Bureau's tests--black blasting powder, liquid oxygen explosives, and various classes and grades of dynamites.

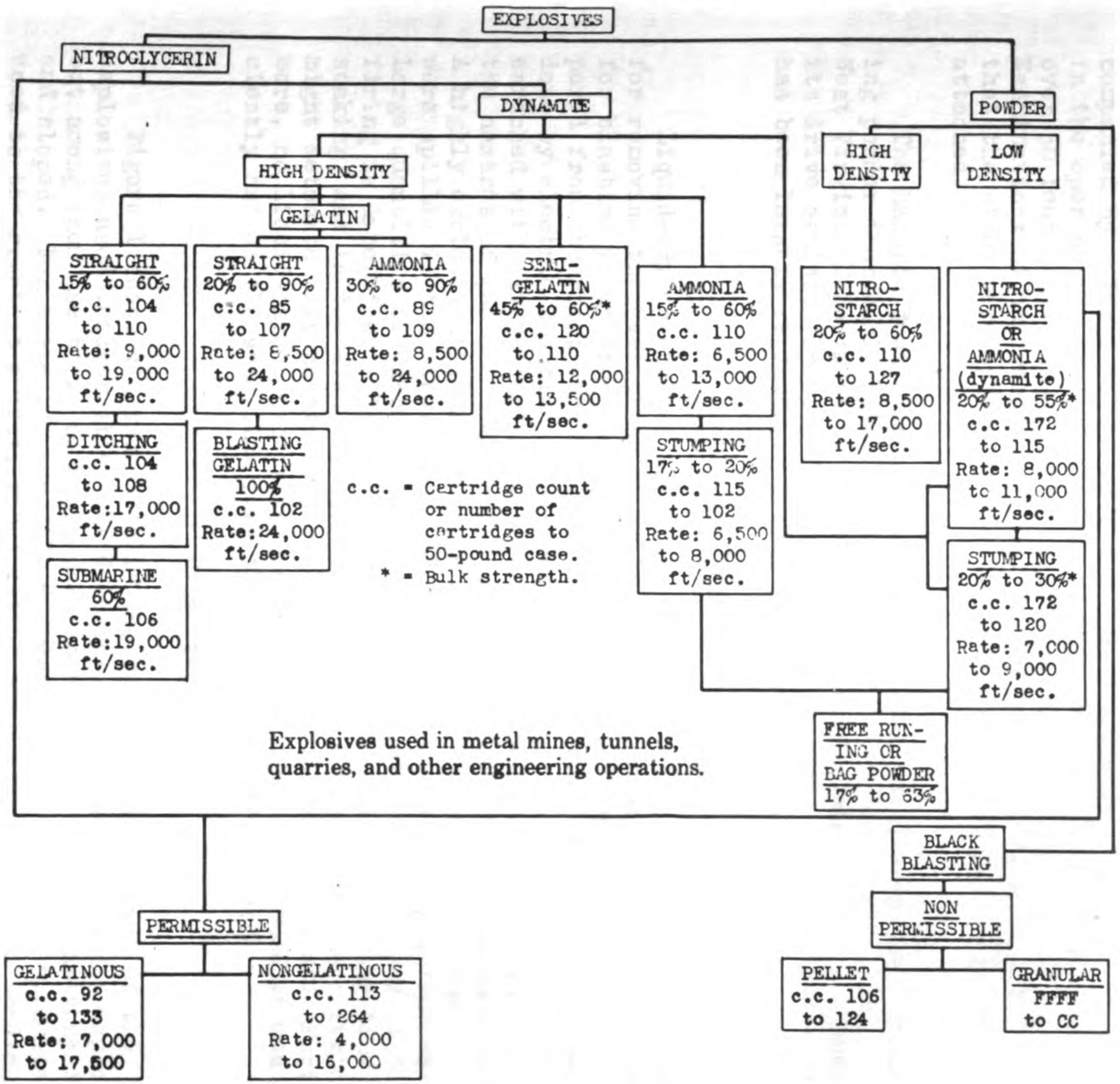
CHARACTERISTICS OF NONPERMISSIBLE EXPLOSIVES

Black Blasting Powder

Black blasting powder--a nonpermissible explosive that contains charcoal intimately incorporated with sodium nitrate and sulphur--is a deflagrating explosive burning rapidly when ignited under confinement. The granular forms of black blasting powder are divided into grades according to the size of grains as separated and collected by sieves having different sizes of round openings. The sizes most usually offered for sale are called CCC, CC, F, FF, FFF, and FFFF. Of these, CCC represents the largest grains, about 5/8 inch in diameter, and FFFF the smallest grains, about 1/16 inch in diameter. The FFF-- about 1/8 inch in diameter--is used to the greatest extent in blasting coal, followed by FF, which is about 1/4 inch in diameter. The grains are sometimes glazed with graphite to render them free-running andto render them some what more impervious to moisture.

Pellet powder--Pellet powder, which was first introduced in the United States about 12 years ago, is unglazed black blasting powder pressed into a cylindrical form having along the axis a hole for the insertion of the means of ignition--fuse or squib. Three-fifths of the black blasting powder is in pellet form, but is no safer to fire in the presence of gas and coal dust than the granular variety.

Comparative tests--Bureau of Mines tests have shown that a 1/10-ounce charge of black blasting powder (granular or pellet) tamped with 1 pound of fireclay stemming, when fired into an explosive mixture of inflammable gas will cause the ignition of an 8-percent gas-air mixture confined in a gallery, whereas all permissible explosives have passed this test with a charge over 70 times as high.


EXPLOSIVES USED IN INDUSTRY

EXPLOSIVES
NITROGLYCERIN
DYNAMITE
POWDER
HIGH DENSITY
LOW DENSITY
HIGH DENSITY
GELATIN
STRAIGHT 15% to 60% c.c. 104 to 110 Rate: 9,000 to 19,000 ft/sec.
STRAIGHT 20% to 90% c.c. 85 to 107 Rate: 8,500 to 24,000 ft/sec.
AMMONIA 30% to 90% c.c. 89 to 109 Rate: 8,500 to 24,000 ft/sec.
SEMI-GELATIN 45% to 60%* c.c. 120 to 110 Rate: 12,000 to 13,500 ft/sec.
AMMONIA 15% to 60% c.c. 110 Rate: 6,500 to 13,000 ft/sec.
NITRO-STARCH 20% to 60% c.c. 110 to 127 Rate: 8,500 to 17,000 ft/sec.
NITRO-STARCH OR AMMONIA (dynamite) 20% to 55%* c.c. 172 to 115 Rate: 8,000 to 11,000 ft/sec.
DITCHING c.c. 104 to 108 Rate:17,000 ft/sec.
BLASTING GELATIN 100% c.c. 102 Rate:24,000 ft/sec.
STUMPING 17% to 20% c.c. 115 to 102 Rate: 6,500 to 8,000 ft/sec.
STUMPING 20% to 30%* c.c. 172 to 120 Rate: 7,000 to 9,000 ft/sec.
SUBMARINE 60% c.c. 106 Rate:19,000 ft/sec.
c.c. = Cartridge count or number of cartridges to 50-pound case.
* = Bulk strength.
FREE RUNNING OR BAG POWDER 17% to 63%
Explosives used in metal mines, tunnels, quarries, and other engineering operations.
BLACK BLASTING
NON PERMISSIBLE
PERMISSIBLE
GELATINOUS c.c. 92 to 133 Rate: 7,000 to 17,500
NONGELATINOUS c.c. 113 to 264 Rate: 4,000 to 16,000
PELLET c.c. 106 to 124
GRANULAR FFFF to CC

PERMISSIBLE EXPLOSIVES ONLY ARE RECOMMENDED FOR USE IN COAL MINES.

Figure 1.– Relationship of industrial explosives.

Hazards in handling and use--In handling and using black blasting powder, the hazards that arise are due to its ready ignition by flame and sparks and the dangers that attend thehandling of the metal keg in which the granular powder is usually stored. The dangerous practice of making a hole in the keg with a pick, bar, or even with a wooden tool has caused many fatal accidents. A miner's open light, when in contact with the exterior of a keg of powder, will cause an ignition in 2 to 3 minutes, accompanied by a large volume of flame. When a keg was fired experimentally in the open at the Explosives Testing Station, the flame scorched objects over 50 feet away. Imagine the hazards of such an ignition underground. Examinations of the remains of many kegs after they had been ignited showed that the sides were opened up and flattened out, sometimes with the ends attached.

The hazards just discussed in the handling and use of black blasting powder thoroughly establish its unfitness for use in coal mines. The West Virginia Department of Mines is to be congratulated on the success of its drive against the use of black blasting powder, which in that State has been largely replaced by permissible explosives.

Liquid-Oxygen Explosives

Liquid-oxygen explosives, which are used to a somewhat limited extent for removing the overburden in coal-stripping operations, are not suitable for blasting in underground coal mines. Liquid-oxygen explosives are prepared from absorbent carbon blacks soaked in liquid oxygen, firing being done by electric blasting caps. Due to evaporation, the air in a mine is enriched with oxygen during the soaking and loading of the cartridges; the hazards of gas and coal-dust explosions therefore are increased greatly. A highly explosive mixture of oxygen and coal dust would be formed if oxygen were spilled in the mine. The soaked cartridges are highly inflammable. Large quantities of extremely toxic carbon monoxide are set free if the firing is done after a lapse of certain limited periods from the time of soaking, and in the event of longer periods of evaporation the cartridges might detonate only partly or just burn--all very great hazards. Furthermore, no liquid-oxygen explosive has been developed that could be used efficiently and at the same time pass the Bureau's gallery tests.

Dynamites

Figure 1 shows diagrammatically the relationship of each of the explosives used industrially. It does not include liquid-oxygen explosives, but among them are those commonly used in sinking shafts and driving tunnels and slopes. For these purposes the 40-percent and 60-percent dynamites are used to the greatest extent, the gelatine and ammonia gelatins leading. In dry work, ammonia dynamites are sometimes used; where the work is not too wet, ammonia gelatin dynamites are used; and for very wet work, the gelatin dynamites are used.

The first dynamite, which was introduced by Alfred Nobel in 1867, consisted of a mixture containing up to 75 percent nitroglycerin and 25 percent kieselguhr, a dope or inert absorbent composed mainly of silica. As kieselguhr is chemically inactive and adds nothing to the strength of the explosive, its strength was about equivalent to the present-day 40-percen straight nitroglycerin dynamite, which contains nitroglycerin and an active dope containing a carbonaceous material mixed with sodium nitrate for absorbing the nitroglycerin, which now usually contains a low-freezing ingredient. Among the carbonaceous materials commonly used are wood pulp, flour, starch, etc. Chalk is added as an antacid or neutralizer, and sodium nitrate is added to oxidize the carbonaceous material, thus adding to the strength of the dynamite.

Straight nitroglycerin dynamites are now rarely, if ever, used in rockwork. The strengths of all other dynamites are rated on the basis of the various grades of straight dynamites, to which they most nearly correspond ballistically, not on their nitroglycerin content. This grading is done on a weight-and-bulk basis, the latter being a stick-for-stick basis. The bulk basis is usually applied to the semigelatins and low-density dynamites, which will be discussed later.

With the exception of the straight nitroglycerin and straight gelatin dynamites, all dynamites contain ammonium nitrate as the principal explosive ingredient. Ammonium nitrate when properly detonated makes an excellent explosive; however, it is necessary to add to it a more sensitive explosive ingredient. The one most commonly used for this purpose is liquid nitroglycerin. A quantity of carbonaceous material is added adequate to absorb the nitroglycerin, which the manufacturer calls "explosive oil." Sodium nitrate is added to oxidize the carbonaceous absorbent. Such explosives are known as ammonia dynamites, and most of them range in strength from 15-percent to 60-percent grade, which makes them suitable for many different kinds of blasting, particularly if the place where they will be used is dry. About 110 of these dynamite sticks are furnished in a 50-pound case. If the places are wet, it may be desirable to use a gelatin dynamite or a straight nitroglycerin dynamite, since ammonium nitrate is very hygroscopic.

The gelatin dynamites contain nitroglycerin gelatinized by the addition of a small percentage of nitrocellulose. Blasting gelatin consists almost entirely of nitroglycerin and nitrocotton. It is made in only one grade--100-percent strength--with about 102 sticks to the 50-pound case, and is perhaps the strongest explosive prepared for industrial use. In making the different grades of gelatin dynamites (20 to 90 percent), blasting gelatin is diluted by the addition of carbonaceous materials and sodium nitrate. The straight gelatin dynamites have a 96-stick count. The ammonia gelatins, that is those gelatin dynamites in which a portion of the nitroglycerin is replaced by ammonium nitrate, range from 30 to 90-percent grade, with a 90-stick count. They are very suitable for wet blasting on account of their water-resisting properties.

There is still another class of explosive quite largely used in wet blasting, known as semigelatin, which contains a smaller proportion of the gelatinized nitroglycerin than other explosives of the gelatinous type. This class of dynamite is rated on a bulk basis ranging from 45 to 60 percent, with a stick count of about 115.

In the ammonia low-density dynamites, ammonium nitrate is used largely as the explosive ingredient; the number of sticks furnished in a 50-pound case ranges from about 115 to about 172, explosives of this class being rated on a bulk basis of 20 to 55 percent, respectively.

CHARACTERISTICS OF PERMISSIBLE EXPLOSIVES

Except for two brands of the gelatinous type, all permissible explosives contain ammonium nitrate. Most of them contain nitroglycerin to sensitize the ammonium nitrate; otherwise, some other sensitizer is used, as, for example, nitrostarch, a solid ingredient. The ammonia permissible explosives correspond closely to the high-count ammonia dynamites especially modified to pass the Bureau of Mines tests for permissibility. This modification is brought about by the proper proportioning of the carbonaceous material and the cooling salts--sodium nitrate or sodium chloride; sometimes both of these are used together. In a general way, the quantities of carbonaceous materials and cooling salts increase with the increase in stick count. The stick count may be as low as 113 and as high as 264 per 50-pound case.

The strength characteristics of permissible explosives have a very wide range, depending somewhat on the stick count. However, explosives should be furnished to the miner for blasting in coal mines on an efficiency basis only. An explosive that might be very suitable for one condition may be entirely unsuitable for another, and the question of profits to the operator on explosives furnished to the miner should be entirely subordinate to these considerations.

High-Count Permissibles

The introduction of low-density permissible explosives has been a gradual one but has been extremely important in increasing the production of lump coal in many mines. Twenty years ago, stick counts for a 1-1/4- by 8-inch cartridge were between 123 and 142 for the ammonium nitrate class, whereas at present there are brands having 227 to 264 sticks per 50-pound case. The use of these very low-density explosives has come about only within the last 10 years. The first very low-density explosive was placed on the permissible list in 1927. Theuse of a properly selected low-density permissible explosive promotes safety in mining coal by restraining the inclination of miners to overcharge the shot hole, while an economical advantage frequently results in the increase in the percentage of lump coal obtained.

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Permissible explosives with stick counts of 225 to 250 have approximately the same strength on a bulk basis as black blasting powder.

Gelatinous Permissible Explosives

The gelatinous permissible explosives, which have stick counts between 92 and 133, were introduced in 1924 for blasting rock in coal mines. In wet mines they have been used for shooting coal.

The gelatinous permissible explosives are gelatin dynamites, usually containing ammonium nitrate but modified to render them safe for use in gassy and dusty coal mines.

Poisonous Gases

All permissible explosives when detonated emit some poisonous gases; therefore, care should be taken to remove these gases by ventilation before the men return to the face after firing a shot. The Bureau of Mines permissible limit of 158 liters (5.6 cubic feet) per 1-1/2 pounds of explosive was established on the basis of firing one shot at a time. If for any reason (as, for example, in driving rock tunnels) large charges of permissible explosives are fired in the round, exceptional precautions should be taken to remove the gases after the blast because only a very few of the permissible explosives emit less poisonous gases than do 40-percent gelatin or ammonia gelatin dynamite, and even when blasting with the latter adequate ventilation should always be provided.

The simplest explosive reaction is that represented by the detonation of a liquid oxygen explosive, carbon and oxygen combining to form carbon dioxide, usually accompanied by some hydrogen and carbon monoxide, which is a poisonous gas. However, nitrogen is liberated from most of the industrial explosives owing to the decomposition of the nitrates they contain. Water in the form of vapor andusually carbon monoxide and hydrogen are formed in varying amounts, depending on the oxygen balance of the explosive. Since some explosives contain sulphur, they may, on detonation, evolve hydrogen sulphide, which is a poisonous gas.

DETONATION OF EXPLOSIVES

Explosives used in coal mines are detonated by means of a primer, a stick of explosive in which an electric blasting cap is inserted.

Electric Blasting Caps

One of the Bureau of Mines prescribed requirements in using permissible explosives is that electric detonators, called also electric blasting caps, shall have a strength of not less than No. 6.

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An electric blasting cap consists of a small, cylindrical capsule usually made of copper. This capsule contains a powerful detonating compound, which, when ignited directly or through some intermediate compound by electrical means, initiates detonation in the explosive (or primer) in which it is embedded. The ignition within the capsule is accomplished by heating electrically a bridge-wire, which is embedded either in a loosely packed detonating charge or in a matchhead. The bridge-wire is made of some non-corrosive alloy having a diameter of approximately 15/10,000 inch. The ends of the bridge-wire are connected between the ends of the leg wires, which are held in a cast-sulphur plug or paper tube. In order to prevent the infiltration into the cap, of water that might render the detonating charge ineffective, the cap is filled above the bridge-wire assembly with a waterproofing composition. Above it is a sulphur seal, which completes the filling of the capsule. In the waterproofed cap for blasting under a high water pressure the lengths of the cap and of the waterproofing compound are increased.

Electric blasting caps are assembled for the trade in a number of ways; however, the most important requirement is that the leg wires must be shunted. Some States have regulations requiring that the shunt be kept in place until the hole has been tamped. This is a good rule to follow, even in the absence of such a regulation or law.

Primers

Only a shot firer should prepare the primer. The electric blasting cap should be inserted in the primer so that the charged end of the electric blasting cap points toward the main part of the explosive charge, because the electric blasting cap produces a powerful shock, which exerts its greatest effect on the charge of explosive away from the charged end of the cap and in line with its longer axis. If there is a lack of care in the preparing and placing the primer, misfires, hangfires, or burnings of the charges in the holes are liable to occur. Failure of the charge to explode may also be due to a number of supplementary causes, such as damp explosive at the cut end of a stick of explosive or dirt between the sticks.

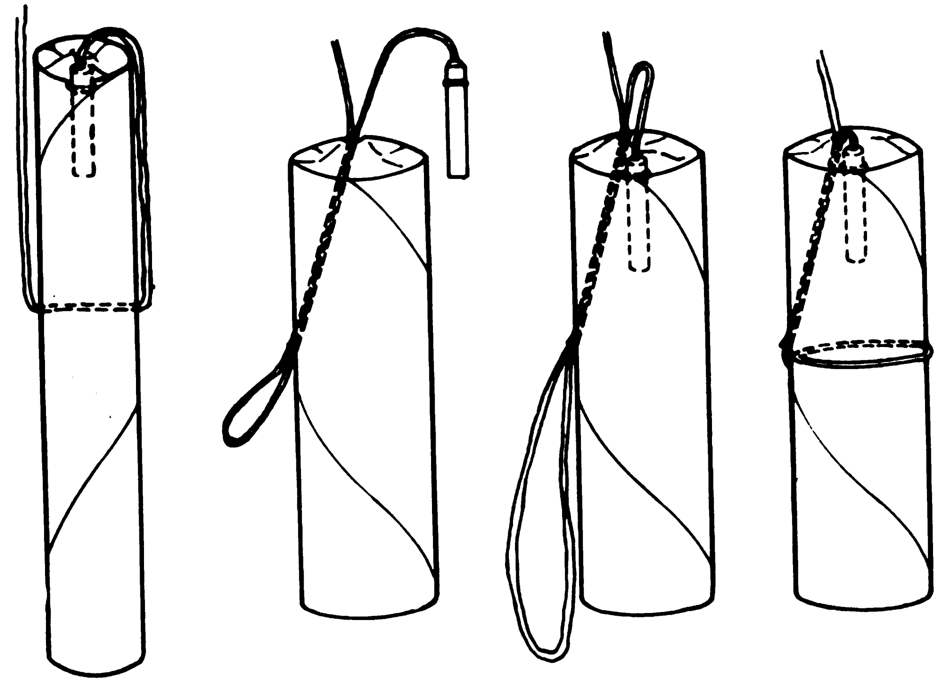
There are a number of methods of preparing the primer that fulfill the above requirements and others that, while not strictly fulfilling them, may be used to meet special or unusual conditions. In making primers it is also important that the electric blasting cap be secured in the primer so that it cannot be pulled out during the preparation and firing of the charge. Kinking of the leg wires or theuse of half hitches to fasten these wires should be avoided wherever possible, as these are liable to cause broken wires or short circuits. The leg wires should be protected as much as possible against injury.

Method 1--One method of preparing a primer when sticks of permissible explosives are 1-1/2 inches or less in diameter is to make (with a wooden skewer) a transverse hole through the stick (fig. 2). This hole is made at a point about 3 inches from one end of the stick and another hole is punched straight in along the center of the stick from the same end and deep enough so that the electric blasting cap can be entirely embedded in the stick. The leg wires of the electric blasting cap are threaded through the transverse hole and then pulled through it until the electric blasting cap is within about 5 inches of the side of the stick. After the electric blasting cap has been inserted in the central hole, the legs should be drawn tight and then brought up along the side of the stick toward the end in which the electric blasting cap has been inserted.

Method 2--The second method is used for a 1-3/4- or 2-inch-diameter stick 6 inches long, the size commonly used in Illinois. This method can also be used for 1-1/4-inch or 1-1/2-inch sticks when the explosive ingredients are not hard or packed tightly; otherwise method 1 or even method 3 can be used. In preparing the primer by method 2, a hole is punched with a wooden skewer in a slanting direction from near the middle of one end of the stick to come out at the side 2 or 3 inches from the end. The legs are now doubled at a point about 10 inches from the electric blasting cap, and the doubled wires are threaded through this hole. A second hole is punched straight into the same end of the stick and as near the center as possible and of such a depth that the electric detonator can be entirely embedded in the stick. The slack on the wires is taken up and the explosive pressed firmly around the electric blasting cap.

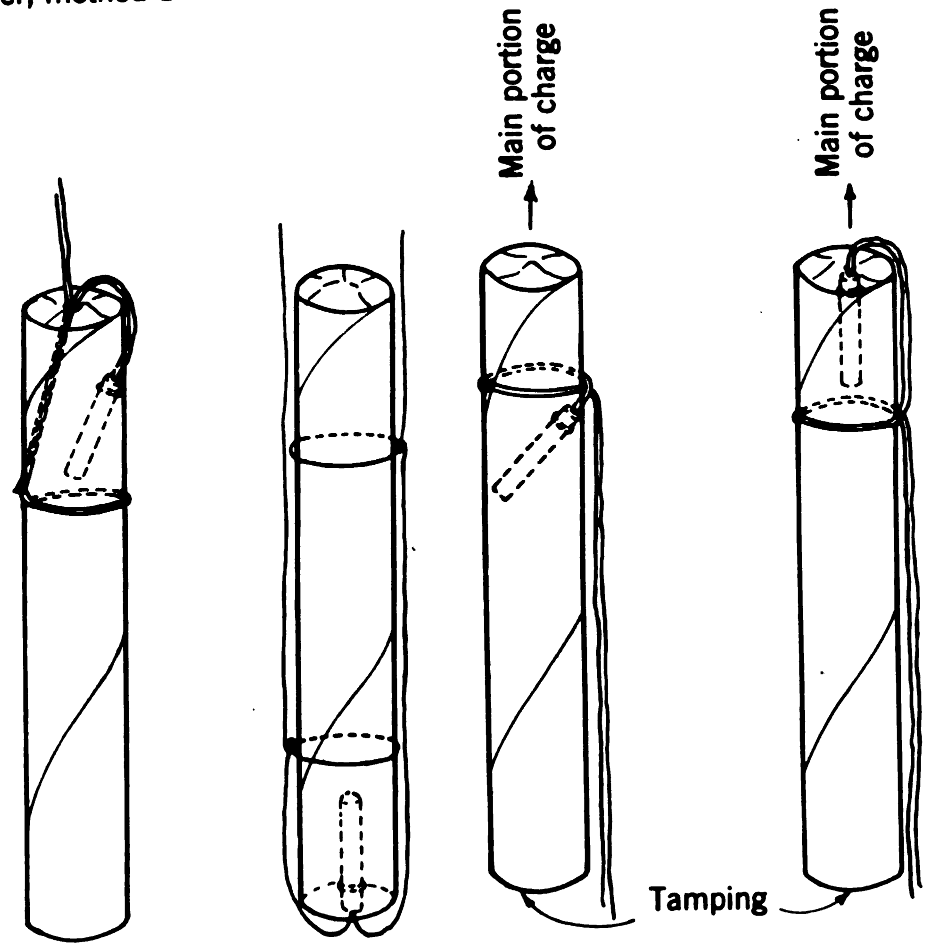
Method 3--The third method is a modification of method 2 and can be used for 1-1/4-inch or 1-1/2-inch sticks when the explosive ingredients are hard or packed tight. In following this method, the hole for the electric blasting cap is a slanting one made at a convenient distance from the end in the side of the stick in such a manner that when the electric blasting cap is inserted, its charged end is near the axis of the stick; otherwise, the procedure is the same as for method 2.

Objectionable methods--The last two methods illustrated in figure 2 are objectionable mainly because in following either of them the charged end of the electric blasting cap points away from the bulk of the charge if the primer is placed last in the shot hole. Furthermore, the charged end of the electric blasting cap is near the side of the stick rather than at its longer axis. This is an undesirable position, because an electric blasting cap should not be placed in any position whereby the pressure of pushing the primer into the borehole may cause the end of the electric detonator to protrude through the cartridge and scrape against the wall of the hole. Friction against the charged end of the electric blasting cap might easily cause a premature explosion.



Primer, method 1

Primer, method 2



Primer, method 3

Primer, method 4

Primers, objectionable methods

Figure 2.- Methods of preparing primers.

Primers for dynamites--In shafts and tunnels where dynamites are used for blasting, the primers can be prepared by methods 1, 2, or 3, when they are placed last in the hole. However, there are conditions under which it may be desirable to place the primer first in the hole, as will be pointed out in this paper in connection with recommendations designed to prevent a certain type of blasting accident in sinking shafts. Where the primer is to be placed in the bottom of the hole, the charged end of the electric blasting cap or delay-electric detonator points toward the main portion of the explosive charge. Method 1 is modified by bringing the legs of the electric blasting cap up along the side of the stick toward the end opposite the one in which the cap is inserted.

Method 4--Another method can also be used; the wires are separated, a half-hitch of one wire is made around the stick about 2 inches from the detonator and the half-hitch with the other wire is made about 2 inches from the other end of the stick, the half-hitches being on opposite sides of the stick. It is possible that the insulation of both wires will be cut at the hitch when the half-hitches are made with both wires together, with the probability of a misfire when an attempt is made to fire the shot. It is therefore an advantage to make each half-hitch separately and at different points along the stick, although the use of half-hitches is the worst feature of this method.

Delay-Action Detonators

Delay-action detonators must not be used with permissible explosives. They can be used to advantage, however, in shaft sinking and in driving tunnels in rock where dynamites are used. In priming with such devices, the practices recommended for instantaneous electric blasting caps usually can be followed. If trouble is experienced with small-diameter cartridges, slit the cartridges lengthwise down one side, place the delay between the halves, then bring the halves together and tie tightly with string.

Blasting Units

Permissible single-shot blasting units are a safe source of electrical energy for firing an electric blasting cap. Storage-battery and dry-cell units are an inductance-free source of electrical energy. Units of the magneto type generate electrical energy by the rotation of a coil or coils of conductors in a magnetic field, and these coils, when rotating, have self-inductance that cannot be avoided satisfactorily. However, the electrical energy in the permissible single-shot units is limited so that they will not yield sparks that can ignite firedamp.

A blasting unit should be cared for properly. If moisture and coal dust reach the inside, the unit may be rendered unfit for use and thus become the cause of misfires. Shot firers and all users of blasting units should be instructed as to the proper method of their care and use. At some mines the shot firer or miner is required to turn in his firing battery when he reaches the surface, and a storage place is provided where the moisture absorbed during the day can be dried out.

In the blasting unit of the generator type the handle should be twisted so as to get the generator up to its highest speed. It is not necessary to "warm up" these units before giving them the final twist. Any defect in a blasting unit should be reported immediately to one of the mine officials. Recently the Bureau of Mines has issued Schedule 16-A, which sets forth the requirements for a multiple-shot blasting unit to fire 10 shots at a time. It is specified that the duration of the current, which is to be of a low tension, shall be 4 to 6 millisecond. One approval has been made under this schedule. The Bureau recognizes that under some conditions special hazards may exist in firing shots separately.

STORING AND DISTRIBUTING EXPLOSIVES

The responsibility of a coal operator begins upon the receipt of the explosive at the mine. Due to the dangers attending the storing, transporting, handling, and use of explosives, it is advisable to detail these operations to as few reliable men as possible.

Magazines

Proper storage facilities are essential, therefore, in designing a new magazine; its size must be decided upon, and suitable materials must be selected for its construction. When the site is chosen, advantage should be taken of hills, which may be used as natural barricades. The site and construction of the magazine should meet the requirements of local and State laws. The distance of a magazine from inhabited buildings and public railroads and highways should not be less than those prescribed in the American Table of Distances.[4] Separate magazines must be provided for electric blasting caps, black blasting powder, and high explosives, which include permissible explosives. Auxiliary or distributing magazines may be provided for the explosives required for one day's use. All magazines should be ventilated and barricaded by either natural or artificial barriers. Proper drainage around magazines is essential. Three types of magazines have been found most suitable for storing high explosives. The first type of magazine is constructed of medium-soft brick laid in cement mortar with the roof bullet-proofed with a sand filling.

In the second type, a weak cement mortar filling between a wooden inner and outer lining is used, the outside of the magazine being fireproofed with not less than 26-gage black or galvanized iron.

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[4] Institute of Makers of Explosives, Amended Pamphlet No. 2 (1919), American Table of Distances; 103 Park Ave., New York.

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The third type may be one of the standard types of portable steel magazines bullet-proofed with weak cement mortar or with 4 inches of brick laid in cement mortar, or lined with wood.

For the storage of black blasting powder a fourth type ofmagazine has been found very satisfactory. The outside is sheathed with 7/8-inch lumber nailed to studding and fireproofed, as is the second type.

Any one of these types of magazines is suitable for the storage of detonators and electric blasting caps.

In localities where deliveries can be made promptly on short notice, a 2,000-pound-capacity magazine is adequate. In an isolated region, where the mine may have a large production, a magazine of 20,000 to 40,00 pounds capacity may be needed. A magazine in which 40,000 pounds of explosive is stored should have outside dimensions of at least 14 by 19 feet, by 8 feet high under the eaves. Such a magazine, when barricaded and located in accordance with the American Table of Distances, should be at least 1,275 feet from the nearest inhabited building, 765 feet from a public railroad, and 380 feet from a public highway. These distances can be reduced about half for a magazine in which only 2,000 pounds of explosive is stored. Unbarricaded magazines must be located at twice the distance that barricaded magazines are located from inhabited buildings and other improvements.

The grounds within at least 60 feet of a magazine should be kept clear ofcombustible materials, such as leaves, dry grass, stumps, and debris as a precautionary measure against fire.

The cases of the older explosive should be placed in the front part of the magazine so that the oldest stock is used as soon as possible. They should also be stored so that a space of a few inches is left between the walls and the cases, thus providing for proper circulation of air in the magazine. To guard against leakage of nitroglycerin from the sticks, the cases should be placed so that the sticks of explosive are stored horizontally and not on their ends.

The floor of magazines should be swept regularly and kept clean. If the woodwork becomes stained with nitroglycerin, it should be scrubbed with a solution of half a gallon of water, half a gallon of wood alcohol, and 2 pounds of sodium sulphide; a stiff broom, hard brush, or mop should be used with plenty of the liquid so as to decompose thenitroglycerin thoroughly.

Opening Cases of High Explosives

Before the explosives are distributed to the miner, the cases in which they are contained must be opened. This should not be done in or near a magazine. Only wooden tools should be used for opening the cases, and no kind of metal tool, such as a nail puller, hammer, hatchet, or chisel, should be employed.

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The lid can be pried off the case by setting the case on end, holding a wooden block where the lid is fastened to the case, and then striking the block with a mallet. The case is then set right-side up and one end of the lid is raised; a wooden rod is placed under the other end and the lid pressed down at the end previously raised; in this way the lid can be separated entirely from the case.

By another method, the case is stood on end, as in the previous method, and then a sharp hardwood wedge placed at a corner of the case about 1-1/2 inches below the lid is struck a sharp blow with a wooden mallet. The operation is repeated at the other corner on the same end. Ordinarily the top will split off clean.

Transportation of Explosives

In transporting explosives either to or from a magazine, just as much care should be exercised on the surface as underground.

Transportation hazards in and around mines can be guarded against best by using a specially constructed insulated car or box for hauling explosives. Such a container should be insulated by lining the inside with thoroughly seasoned wood over which sheet asbestos should be placed. Another lining of wood should cover the asbestos. The wooden lining should be fastened by wooden pegs. No metal parts, such as bolts or nails, should be exposed inside the container.

If an insulated car is drawn by an electric motor, an insulated coupling should be used between the powder car and the car to which it is coupled. At least two empty cars should intervene between the powder car and the trolley locomotive.

A storage-battery locomotive can be used in States that require all current in trolley wires and other conductors to be cut off when explosives are hauled.

Electric blasting caps and explosives should be transported together only in adequately separated compartments. Men should not be allowed to ride on any cage, skip, bucket, or car in which explosives are carried, except such employees as are necessary to oversee their handling, and such employees must not smoke while engaged in this work. Tools, timbers, and other materials must not be carried in the car with explosives. The laws of some States permit the miners to carry their own explosives into the mine, and the shot firers may carry the electric blasting caps. The container for either the miner's supply of explosives or for electric blasting caps should be made of an electrically nonconducting material, such as wood, fiber, or canvas. All explosives should be apportioned into the individual containers at the distributing magazines on the surface. The containers should be stored underground in portable, tightly locked wooden boxes, each having a lid that laps over the sides of the box and that is strongly hinged. Battens should be placed over all joints so that the explosive may be protected from sparks, flame, and water. No electric blasting caps, tools, or pieces of metal, matches, or oily material should be allowed in the wooden boxes provided for explosives. The powder box should be placed in a crosscut or recess, which should be at least 60 feet from the working face and so situated that there will be no danger of the box being struck by flying pieces of coal or rock. An alternative method for storing the miner's explosive and caps when in individual containers is to store them in cubbyholes in a crosscut. The container for the explosive may be in a cubbyhole on one side of the crosscut and the one for the blasting caps on the other side. These cubbyholes should not be too close to trolley wires or tracks.

It is the custom of some miners to cache their explosives and electric blasting caps under flat pieces of slate in the gob, but this is a dangerous practice and should be forbidden. Explosives and electric blasting caps should not be left on the floor near a rib because instances have been reported in which explosions of gas and coal dust have been started when the roof has fallen on explosives so placed.

PREMATURE EXPLOSIONS

Premature or accidental explosions at the working face usually are due to improper manipulation. A stick of explosive should not be forced into a hole, particularly if it is the primer with blasting cap embedded in it. Wooden tamping bars only should be employed.

Sensitiveness of an Explosive to Friction

Even if a wooden tamping stick is used, the explosive must not be too sensitive to frictional impact. Explosives that do not pass the Bureau of Mines pendulum friction test are not suitable for use in blasting operations because they are liable to explode while being loaded into a hole. Like other physical characteristics of explosives, we can only consider them in a relative sense.

Drilling into an Unexploded Charge

Almost all explosives will explode if subjected to a blow of sufficient intensity, (for example, if drilled into). In a recent accident while a shaft was being sunk a drill struck an unexploded portion of a charge of explosive that was lodged in a "boot" left after the previous round had been fired. Possibly the upper portion of the hole was dislodged by the firing of adjoining holes, the bottom of the charge thus being cut off before it could be fired from the upper portion of charge. One of the ways of avoiding such unexploded charges is to place the primer in the bottom of the hole. Other lessons taught by an investigation of this accident were, first, that where shots are fired in series be sure that there is no variation in resistance of bridge wires of the electric blasting caps. It is impossible to have this assurance if caps furnished by two or more different manufacturers are used in the same circuit: second, the circuit should be examined with a testing galvanometer just prior to firing, and each individual electric blasting cap should be tested before any attempt is made to use it.

Hazards of Frozen Explosives

Today, accidents due to handling frozen explosives are almost unknown, although not many years ago the use of explosives in winter was considered hazardous because it was necessary to thaw them before use, and too often this was undertaken in improper ways. As virtually all dynamites and permissible explosives contain nitroglycerin, which at ordinary temperatures is a viscous liquid, they will freeze to a solid at temperatures below 55°F. Frozen explosive becomes very insensitive to explosion by means of a primer; singularly, however, while being thawed it develops extreme sensitiveness in handling, with the result that serious accidents--many of them fatal--have occurred from "thawing dynamite."

To overcome this hazard, nitroglycerin is mixed with some material to to lower its freezing temperature, such as liquid nitrotoluene, nitropolyglycerin, and the more recently adopted ethylene-glycol-dinitrate, which has been made available by modern chemical progress.

Short-fusing

Short-fusing causes many premature explosions of the charge because of insufficient time to place the charge in the hole properly, tamp, and at the same time get away to a safe place before the explosion occurs. However, this hazard does not exist when permissible explosives are used with electric blasting caps, as prescribed by the Bureau of Mines.

Insensitiveness of Explosives

Partial detonation of a charge of explosive or burning of the charge is more likely to be due to the insensitiveness of the explosive, and like a misfire, is rarely due to a faulty electric blasting cap. While occasionally some explosives may be abnormally insensitive when delivered to the user, an otherwise sensitive explosive may become insensitive by improper or too prolonged storage. Permissible explosives deteriorate rapidly when taken into coal mines owing to the relatively high humidity. The miner often requires only a portion of a cartridge to be used with one or more whole cartridges. Thus, the remaining portion of the cut cartridges may be returned either to the miner's carrying container or to a less-suitable place, where the cut end will absorb moisture. Most of the ingredients of permissible explosives, particularly ammonium nitrate, are highly hygroscopic and will absorb and retain moisture. Even when small amounts of moisture are absorbed, there is always a marked decrease in sensitiveness. In most instances where the increase of moisture reaches 3 per cent, the explosive is very insensitive and is unfit for use in blasting. The storage of explosives in mines should be limited to the shortest possible period and should not extend beyond one shift.

Misfires--While misfires may sometimes be due to faulty electric blasting caps, they are more likely to be caused by lack of care by the shot firers and of proper direction and supervision by mine officials as to methods of firing. To avoid misfires, firing batteries and all other shot-firing equipment should be kept in perfect condition at all times.

In making connections between the legs of the electric blasting caps and lead wiresor the firing cable, avoid merely hooking the ends together, because an electric current may not flow through such a connection. Unless the wires are properly twisted together, misfires probably will result. Above everything else, do not shoot from the trolley wire, because if any gas is inthe place, or the place makes gas, an arc from the ends of the lead wires near the face may ignite a gas-air mixture. Furthermore, disconnections at the trolley wire cannot be made the instant the cap fires. Rubber-covered firing cables tendto reduce misfires. The size of the copper wire should **not** be less than No. 14 B & S gage.

Action of Explosives

A question often asked is whether dynamite acts down and black blasting powder acts up. As a matter of fact, the action of both of these explosives is equal in all directions. If we took a stout wire screen supported horizontally and tied to it two sticks of dynamite at separate places--one on the underside and the other resting on the screen--upon firing the dynamite we would get holes identical in appearance, except that it would be evident that the energy exerted in making each hole was applied in opposite directions, one hole being made from underneath and the other from above the screen.

BLASTING WITH PERMISSIBLE EXPLOSIVES

Preparing the Face

If the best blasting practices are followed in using permissible explosives, it is doubtful whether, as is so often claimed, a larger proportion of lump coal will be obtained by using black blasting powder. However, it will be necessary to standardize all operations involved in drilling and blasting. Before this can be done, consideration should be given to such conditions as the thickness and pitch of the coal bed, the position of partings and their thickness and extent, the toughness or brittleness of the coal, and the direction and nature of the cleats.

In cleaning up a working place, all overhanging faces should be barred down and the corners squared by trimming.

Cutting

Shooting off the solid is done where no cuts or shears are made. In such a case there is but one free face. An additional free face is provided by making an undercut, topcut, or sideshear. An undercut is generally the most desirable form of cut. A middlecut or overcut may be used instead of an undercut when some particularly physical conditions such as the presence of shale or bone bands (which may be removed by the cut) are present. Bad roof conditions can often be controlled by overcutting.

As many free faces as feasible should be prepared. A middlecut or middleshear provides two additional free faces. The more free faces, the better the chance for the explosive to bring down the coal and for the amount of energy to be exerted by the explosive to be lessened. Not only is a blocky and firm product obtained, but safety also is increased. In cutting a room or entry there must be no sumping-in of the coal-cutter in a direction other than parallel with the line of sights. Similarly, the pulling out of the cutting machine after it has cut across the face must be maintained parallel to the line of sights. Except in working places where arc-wall machines are used for cutting, the best results are attained when the cuts are of uniform depth and square at the back corners.

Snubbing

Snubbing increases the height of the undercut and provides an opportunity for the front portion of the coal to roll forward when loosened by the blast. In snubbing, a wedge-shaped portion of coal is removed just above the undercut, about 10 to 18 inches high in front and extending back until it tapers out at about half the depth of the undercutting. This operation usually is done by handwith pick andwedge, although sometimes it has been done mechanically. The snubbing operation can be modified by shooting low short holes. Sometimes snubbing pans are placed in the kerf and by shooting the holes the coal released falls on the pans. The pans are then hitched to a mine locomotive and pulled out from under the cut.

Cleaning out Cut

Close attention must be given to the cleaning out of the cut so that all coal dust and other broken coal are removed before shooting is begun. A scraper or long-handled shovel is the best tool for this purpose. The coal thus removed should be loaded into mine cars and removed from the working place before blasting is begun. This will reduce the dangers arising from the presence of coal dust.

Drilling and Placement of Holes

The holes should be drilled only after the working place has been cut or sheared, otherwise their placement may not bear the proper relation to the cut. The number of holes and their placement are by far the most important considerations in successful blasting. At a room face their number may range from two to five or many more. In many mines working the Pittsburgh bed, only two holes are used, one at each rib.

It has been observed in mines where very thick beds of coal are worked that a large proportion of the fine coal is due to an insufficient number of holes that may have exceeded the permissible limit of 1-1/2 pounds per hole. Where the number of holes per round is increased, the total weight of explosive in the round may be less than the weight of that which would have to be employed where fewer holes are used. Blown-out shots may result if the holes are deeper than the cut or shear. The holes may parallel the side of the undercut but, due to its change in direction near the back of the cut, the end of the hole may be on the solid. "Dead holes" drilled entirely on the solid are very dangerous because the explosive is liable to expend almost its entire energy into the working place.

In coal beds corresponding to and similar in physical characteristics to those of the Pittsburgh bed, each rib hole usually can be placed 12 inches from the rib and the same distance below the roof. However, in the tougher coal beds of southern Illinois, as represented by the No. 6 bed, it is better to increase the distance between the rib and hole to 2 or even 3 feet. The most favorable blasting in both instances is when the rib holes are almost flat and parallel to line of sights. The holes should not be drilled into the roof, as it may be broken and rendered unsafe for future driving of the place.

Charging the Hole

Before a hole is charged, the cuttings should be scraped out of it and the hole measured to see that it is not on the solid. In charging a shot hole, all the sticks of permissible explosive used should be pushed to the back of the shot hole at the same time by means of a wooden tamping stick, the primer stick being placed last in the hole.

Air-Spacing and Low-Density Explosives

Cushioned blasting or air-spacing has been used to a considerable extent as a means of increasing lump coal. The necessity for its use does not exist to the same extent as formerly, not that the demand for lump coal has decreased but because we have available low-density or high-count permissible explosives. By using them the energy can be distributed along the shot hole without changing the diameter of the stick. This is a decided advantage over reducing the diameter of the stick. The smaller the diameter, the more likely it is that the explosive may not detonate completely. Experience has shown that less weight of a low-density explosive as compared with one of a higher density is required to bring down the coal, and if the lower-density explosive brings down the coal properly, there will be a larger percentage of lump coal.

If one has been using in a hole, say, two sticks of a very high density explosive of about 113 stick-count and changes to one of 225 stick-count, for the same amount of energy four sticks, or twice the length of charge, would have to be used, although it is quite likely that this could be reduced to 3-1/2 sticks. It may be found, however, that four sticks will not bring down the coal because of too widespread a distribution of energy along the shot hole. In such an instance, it is doubtful whether a charge of more than four sticks would be any more successful, and therefore it might be advisable to try an explosive with a stick-count of 170. In certain beds of coal very low density explosives cannot be used, particularly if the beds are tough and hard.

Tamping and Firing the Shot

The hole should be stemmed to the collar with incombustible stemming, such as clay or shale, which should be tightly tamped. Tight stemming is necessary to prevent possible issuance of flame.

The foregoing recommended procedure is taken from Decision 12 of the Mine Safety Board of the Bureau of Mines. This decision further recommends that those who fire the shots shall be certified men and that they shall know what each hole contains before firing it, either by charging it themselves or having it charged under their immediate supervision. The above decision also recommends, as an additional precaution, that where the organization of the mine and other conditions permit, shot-firing with explosives shall be done when all men other than those authorized to fire shots are out of the mine. An alternate safe method is to fire electrically and simultaneously from the surface after everybody has left the mine. Before and following each shot in a gassy and slightly gassy mine, examination for gas shall be made.

The shunt on the legs of the electric blasting cap should be removed only after the hole is tamped.

The shot firer then connects the firing cable to the legs of the electric blasting cap. He should not unreel the cable before making these connections. The cable, which should be 100 feet or more in length, is now unreeleduntil the shot firer reaches a place where he is guarded properly from flying pieces of material from the blast. Neglect by the shot firer or other workers in the immediate vicinity to take proper shelter causes many fatalities and injuries. Precautionary rules to avoid accidents from the latter are usless unless observed.

After the shot firer has removed the twist from the ends of the cable he can connect the blasting unit, calling "fire" before and after making the connection. Every precaution should be taken to assure himself that everybody in the immediate vicinity of the blast has taken shelter.

After the shot has been fired, the shot firer should disconnect the cable from the blasting unit, twist the two wires of the cable together, and then reel the cable for moving to the next place.